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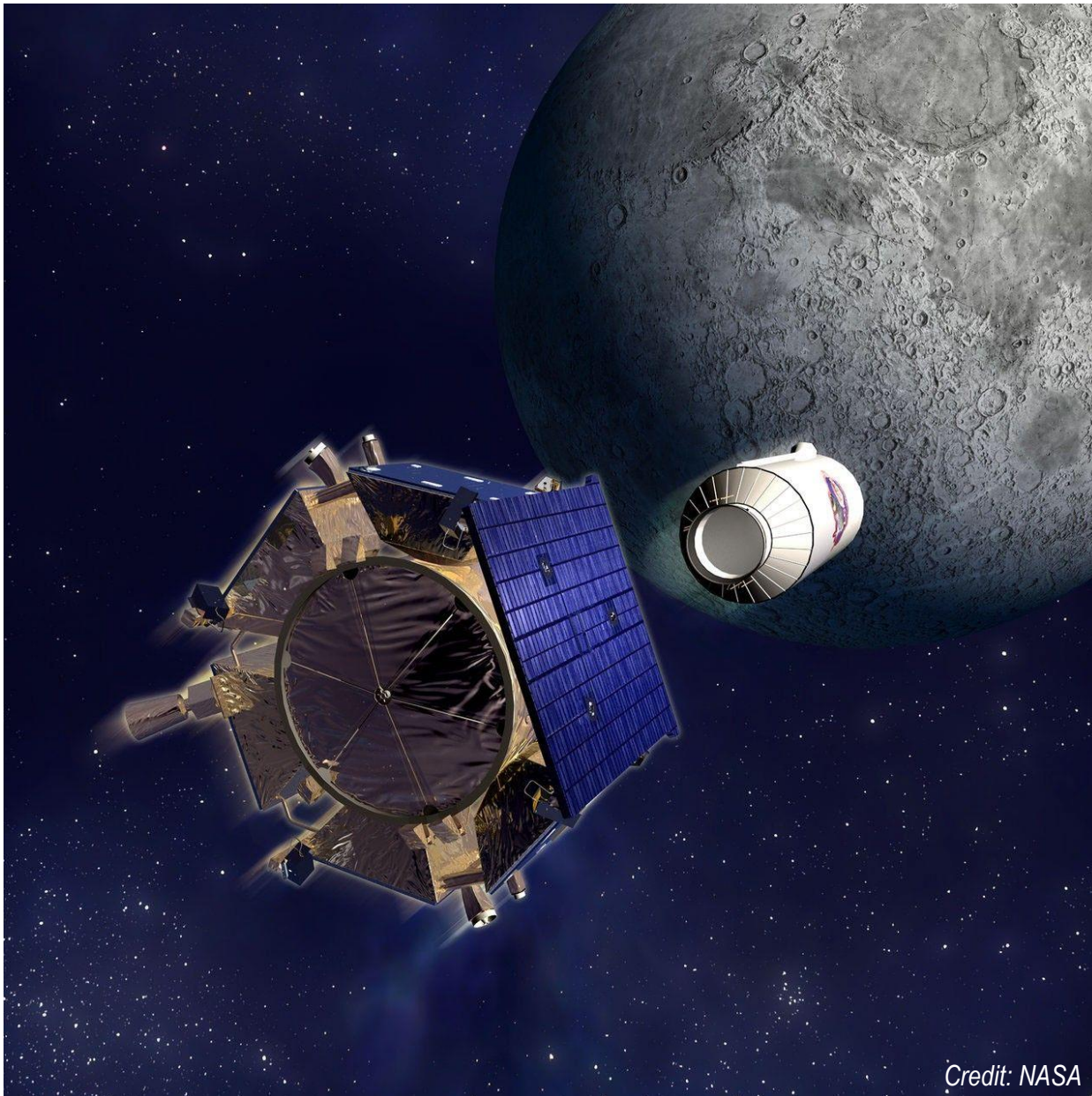
PVEx Design and Lessons Learned for the Lunar Capillary Absorption Spectrometer (LuCAS)

Isabel King, Research Engineer
6/4/2025

Lunar Volatiles



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Credit: NASA

Table 2. Abundances derived from spectral fits shown in Fig. 3. The uncertainty in each derived abundance is shown in parenthesis [e.g., for H₂O: 5.1(1.4)E19 = $5.1 \pm 1.4 \times 10^{19} \text{ cm}^{-2}$] and was derived from the residual error in the fit and the uncertainty in the radiance at the appropriate band center.

Compound	Molecules cm ⁻²	% Relative to H ₂ O(g)*
H ₂ O	5.1(1.4)E19	100.00%
H ₂ S	8.5(0.9)E18	16.75%
NH ₃	3.1(1.5)E18	6.03%
SO ₂	1.6(0.4)E18	3.19%
C ₂ H ₄	1.6(1.7)E18	3.12%
CO ₂	1.1(1.0)E18	2.17%
CH ₃ OH	7.8(42)E17	1.55%
CH ₄	3.3(3.0)E17	0.65%
OH	1.7(0.4)E16	0.03%

*Abundance as described in text for fit in Fig. 3C.

Colaprete, et al. (2010)

- ▶ Lunar volatiles are more than just water ice
- ▶ Characterizing composition and abundance is important to building ISRU systems
- ▶ Isotopic ratios of these molecules tell us about their origin, which can inform our understanding of key parameters like spatial distribution and texture

Capillary Absorption Spectrometer (CAS)



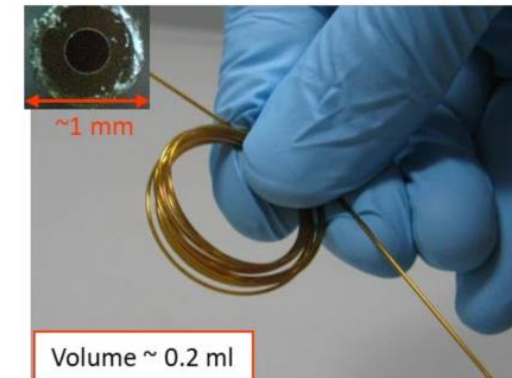
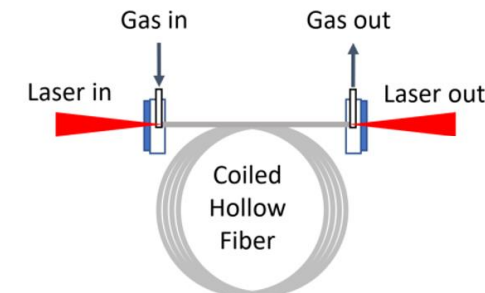
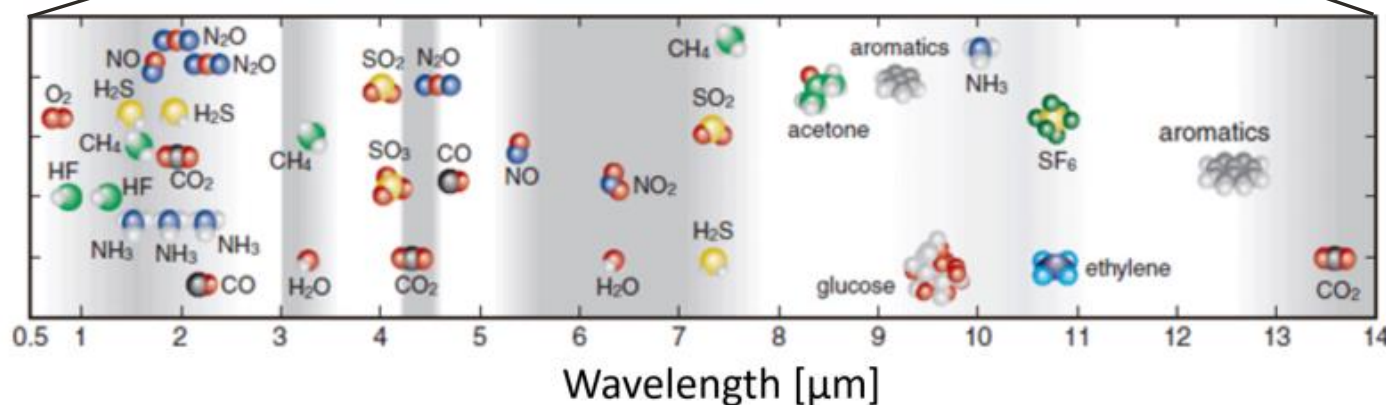
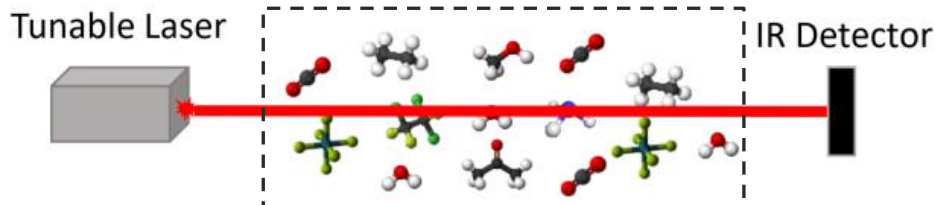
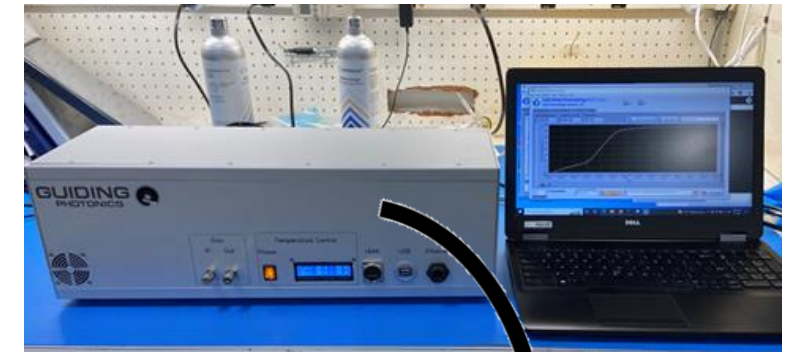
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- ▶ Trace gas and isotope analyzer utilizing a low-volume (~1 mL) compact gas cell
- ▶ Mid-IR wavelength range enables unique identification of molecules, differentiating both species and isotopologues
- ▶ Identifies abundance of key volatiles of interest for the lunar surface – notably H_2O , H_2S , NH_3 , CO_2 , CH_4 (and more!)



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Kriesel, et al. (2023)

Lunar Capillary Absorption Spectrometer (LuCAS)



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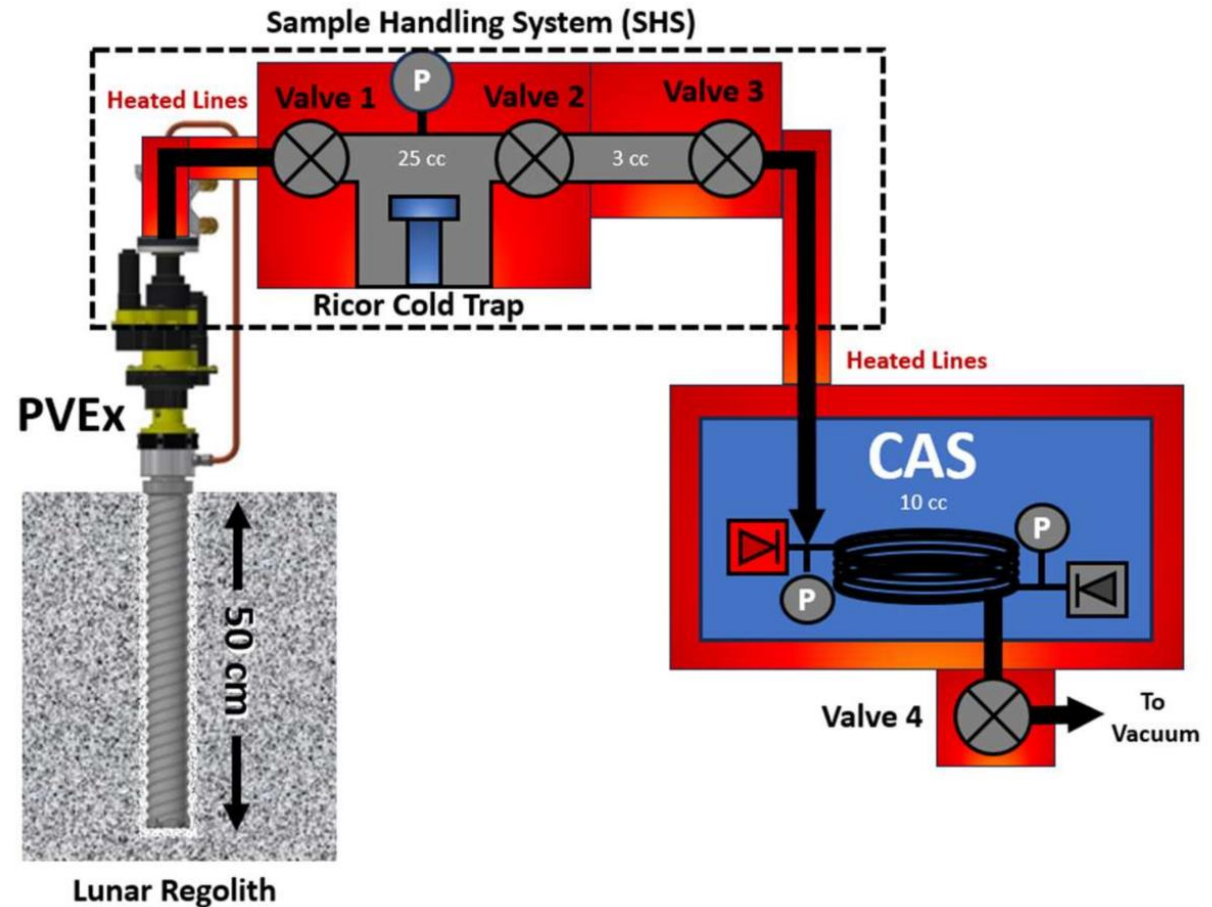
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LuCAS is an end-to-end system for volatile extraction, collection, metering, and analysis on the lunar surface



Lunar Capillary Absorption Spectrometer (LuCAS)



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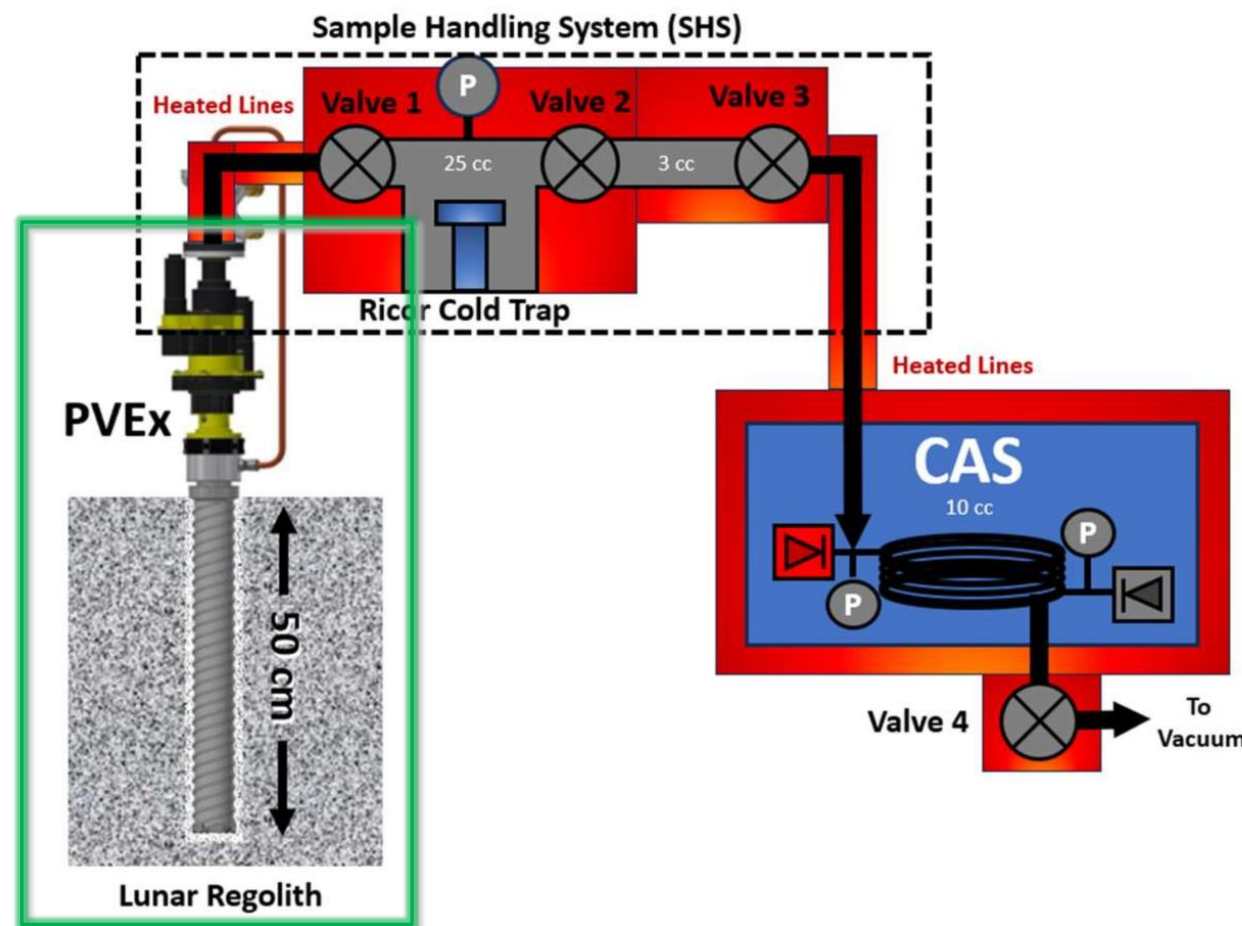


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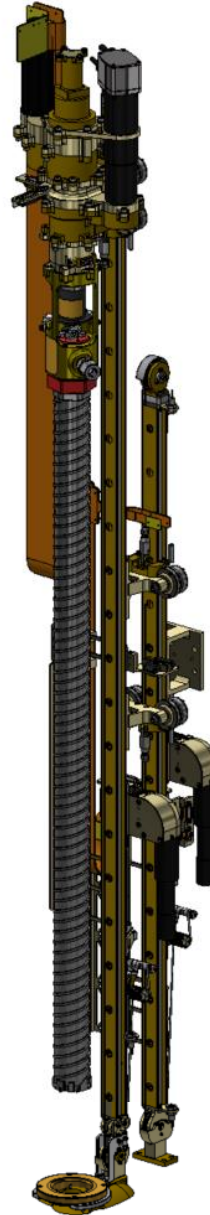
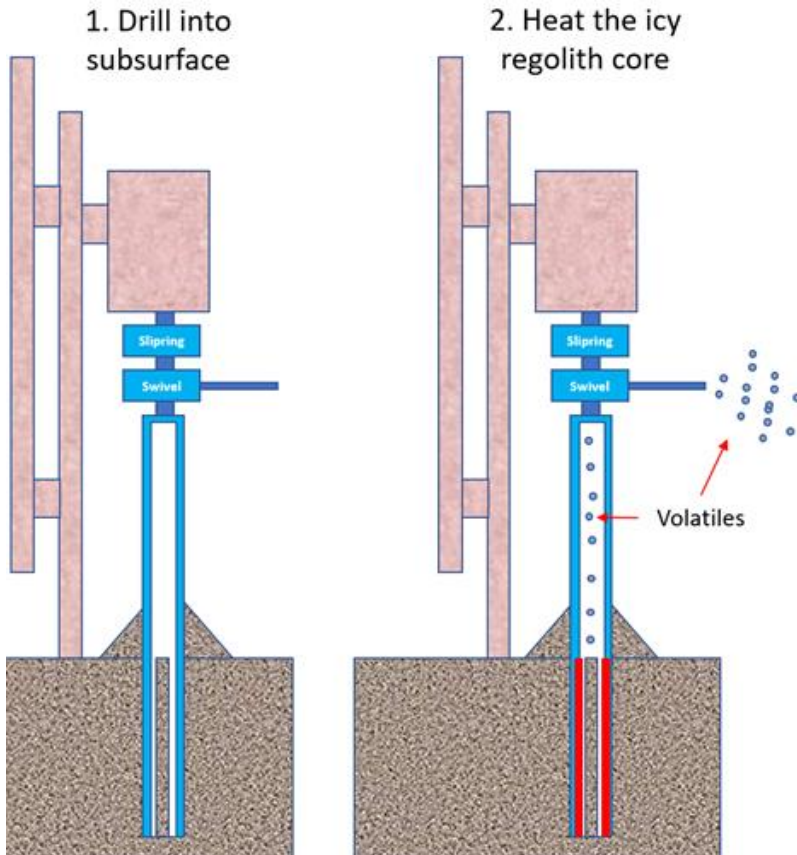


PVEx Overview



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- ▶ 1-meter rotary percussive “coring” drill
- ▶ Auger contains a heater to volatilize ices in-situ
- ▶ Volatilized gas flows up through the drill string to a cold trap where it is collected



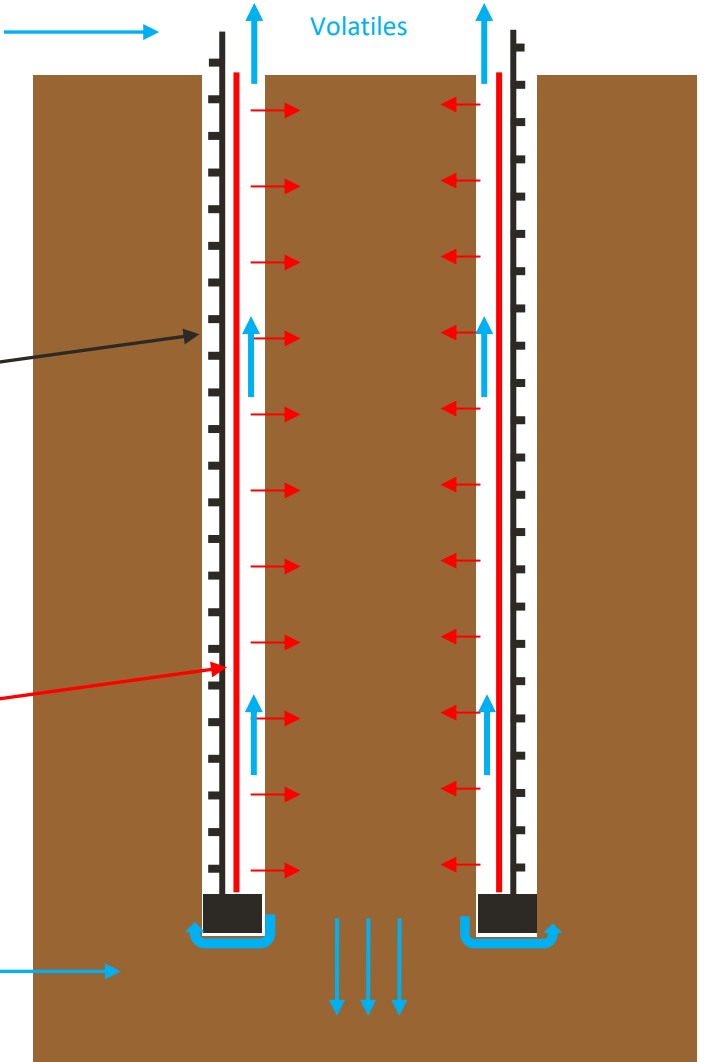
Volatile Extraction Concept

Volatiles travel more freely in gap created by cutting teeth

Auger with flutes and cutting teeth

Inner sleeve with heater

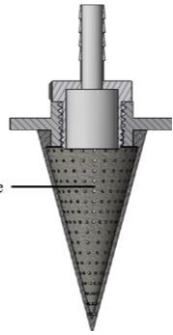
Volatile flow is more restricted downward



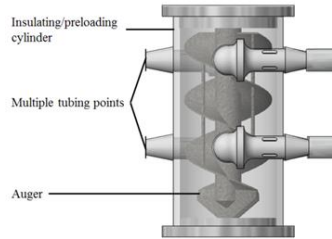
PVEx Development Timeline



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Perforated cone



Insulating/preloading cylinder

Multiple tubing points

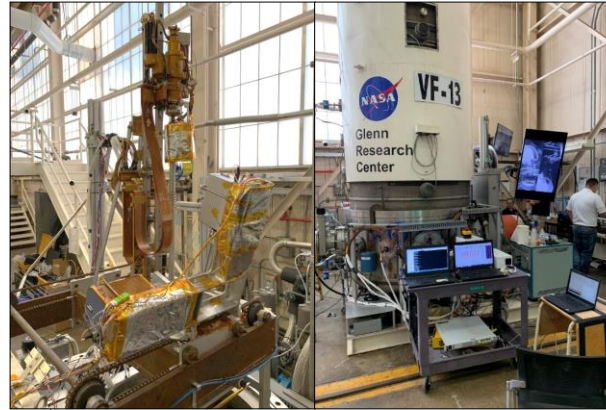
Auger

SBIR Phase I

2015

2016 – 2018

2019

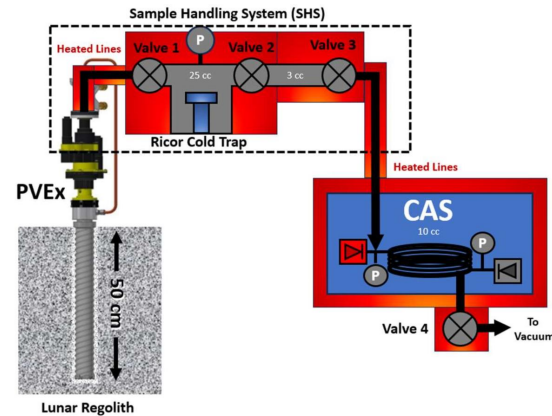
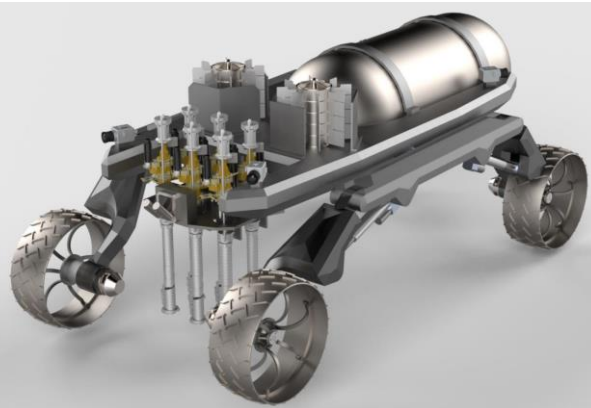


GRC Testing

2024-2027

LuCAS DALI

SBIR Phase II

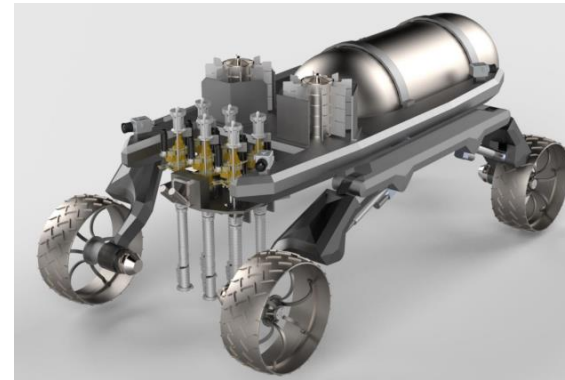
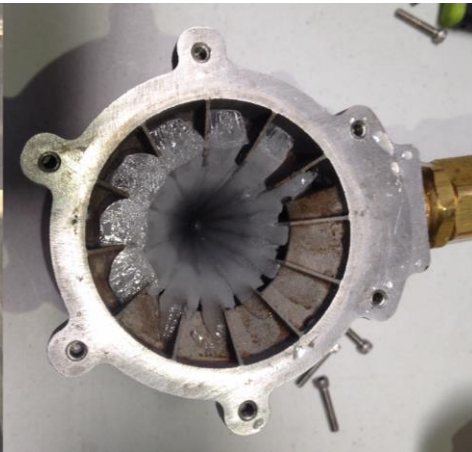


SBIR Results



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- ▶ Developed 50 cm long, 2-inch inner diameter PVEx drill
- ▶ For lunar conditions (-20C, vacuum, NU-LHT-2M, 4-12 wt.% ice), consistently getting **~50% water collection efficiency**



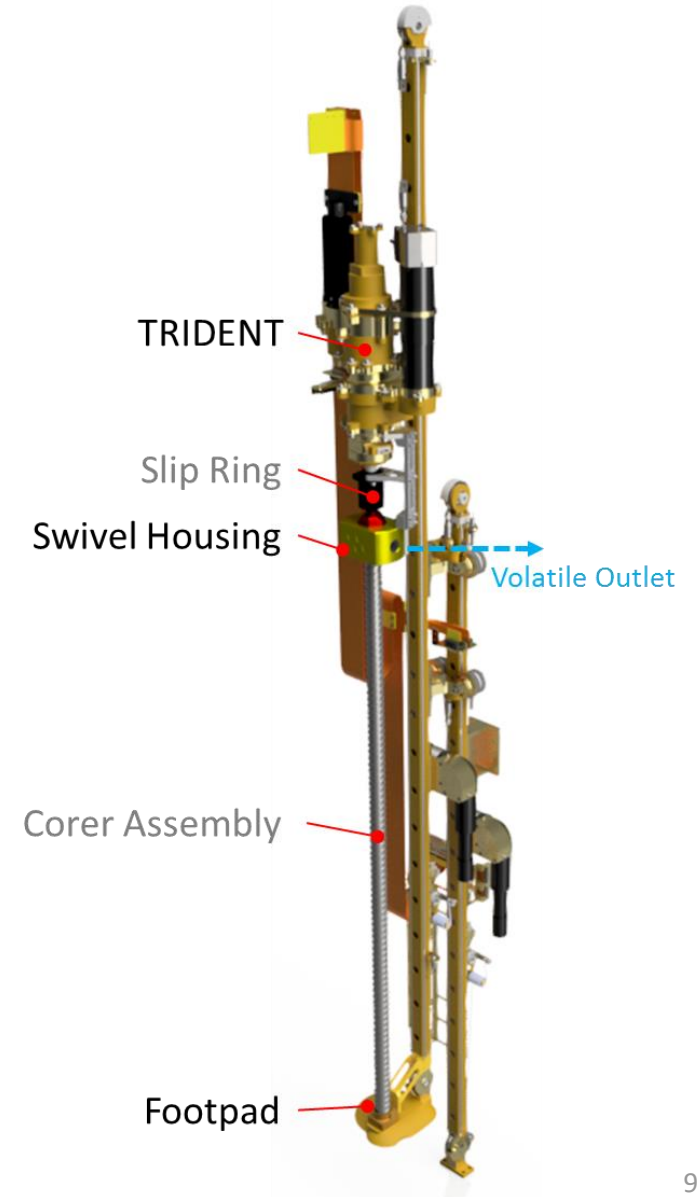
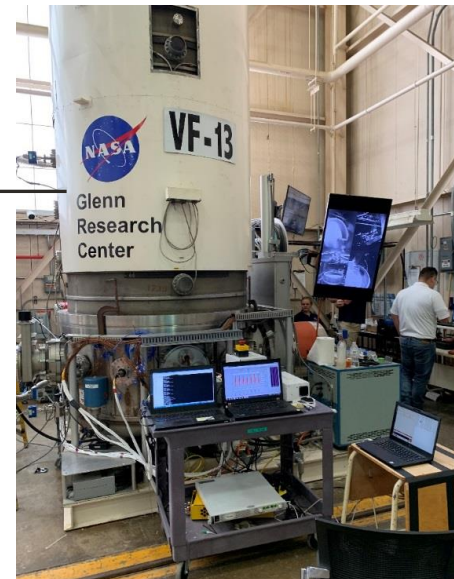
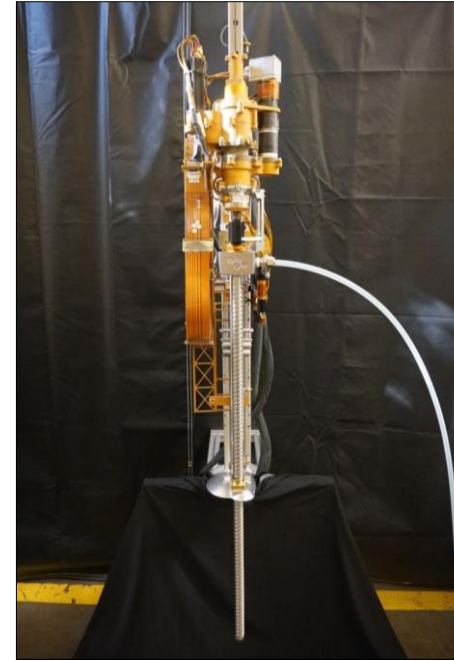
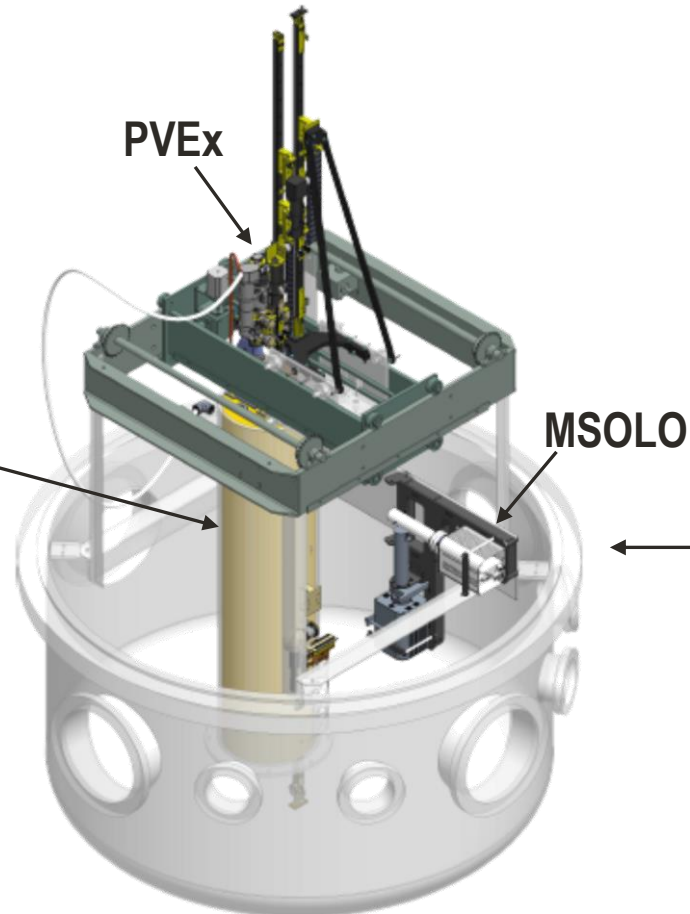
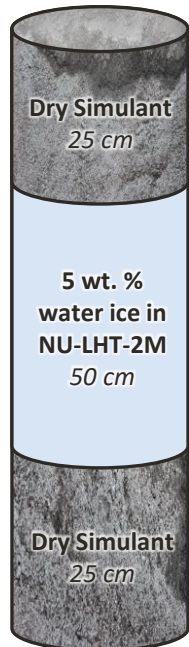
GRC Results



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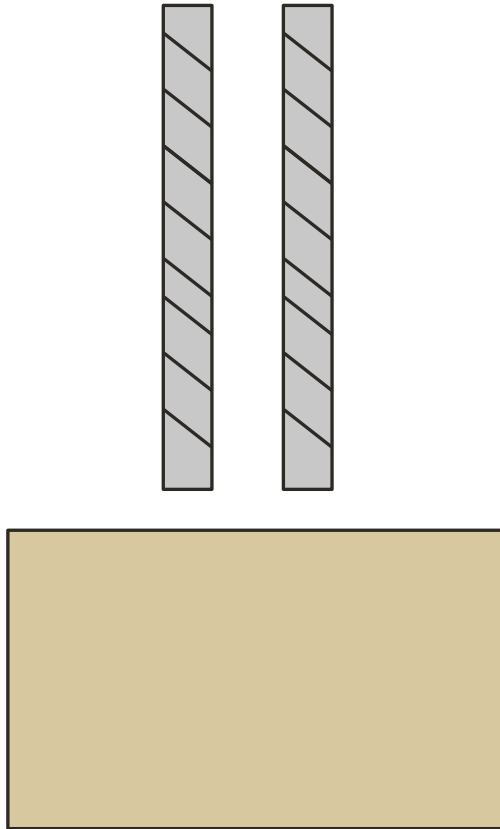
- ▶ Updated PVEx design to be lower mass – 0.75" inner diameter
- ▶ Tested with MSOLO in VF-13 chamber at GSC (10^{-6} torr, -150C)
- ▶ MSOLO volatile readings were **inconsistent with results that were expected by depth**

Icy regolith simulant bin



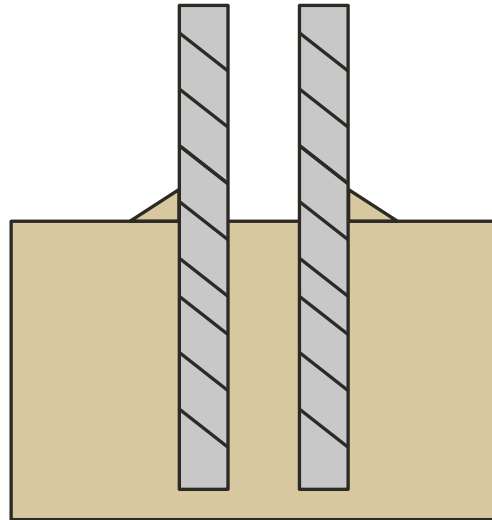
Theory from GRC Testing

Before Drilling



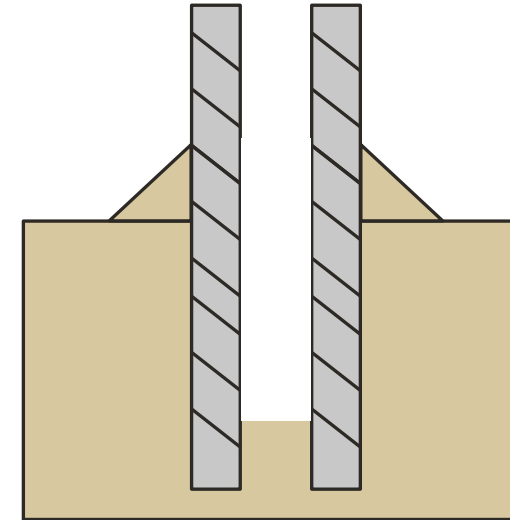
After Drilling

Good Result: core is retained inside auger



After Drilling

Bad Result: core is not retained inside auger



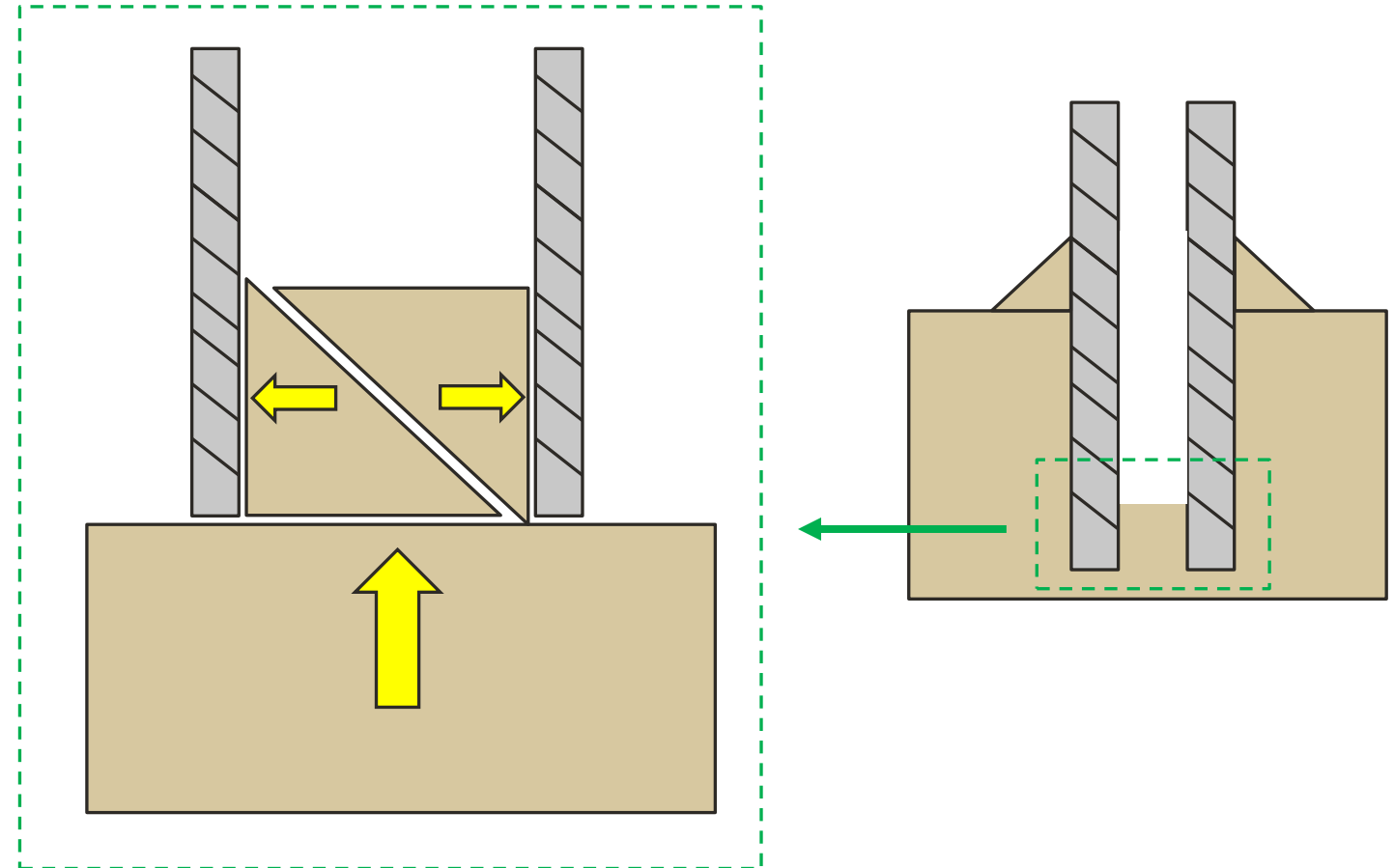
Explanation for GRC Results



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- ▶ We believe the smaller ID PVEx (ID=0.75") used in GRC testing did not capture full core due to bridging inside the auger
- ▶ The soil in contact with auger walls sees friction, and when more material is pushed up against it during drilling, the core fails in shear. This creates a "plug" at the bottom of the drill that limits material that can enter.
- ▶ This problem is worse for coring systems with higher inner surface area to soil ratio (i.e. small ID)

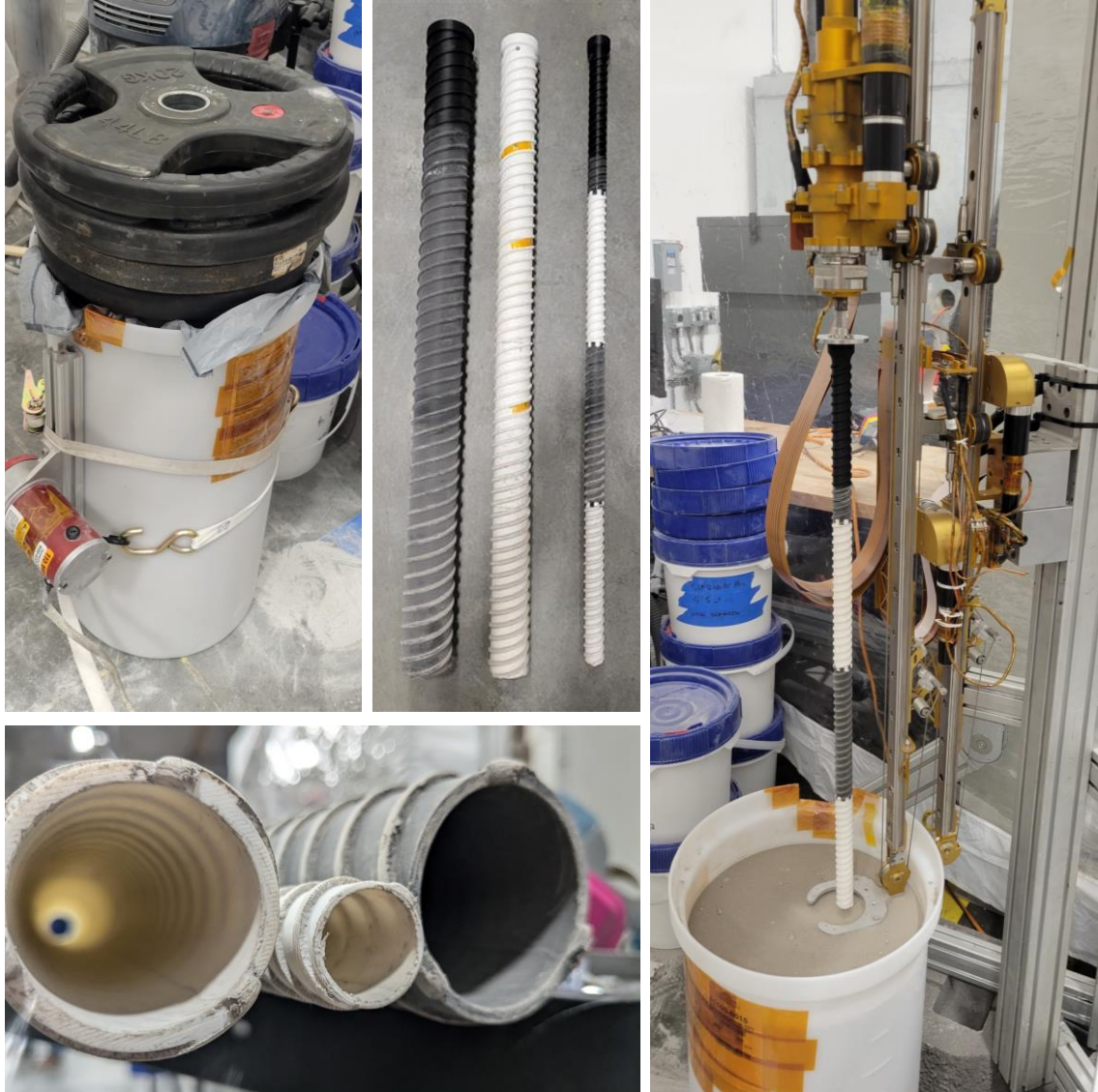
During Drilling



LuCAS Development



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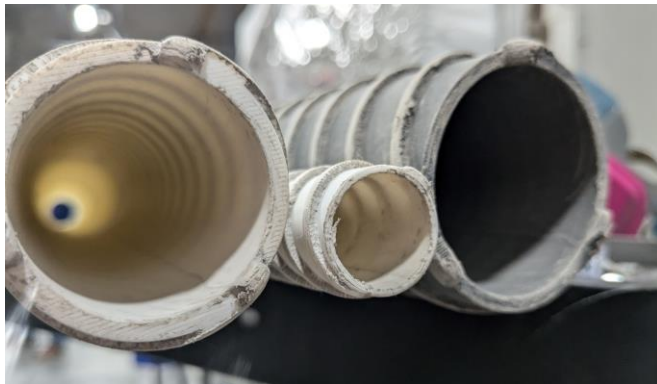
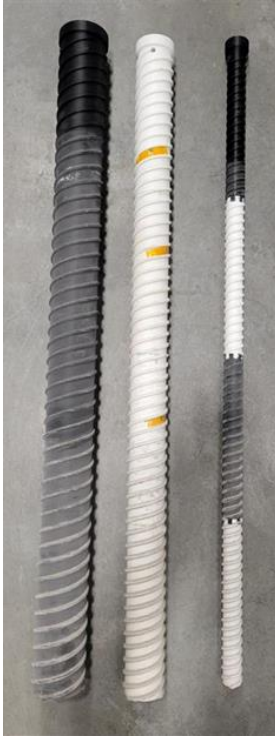


- ▶ DALI presents an opportunity to test and correct this failure mode
- ▶ 3D printed three augers:
 - ▶ 2" ID (same as SBIR testing)
 - ▶ 1.5" ID (intermediate size)
 - ▶ 0.75" ID (same as GRC testing)
- ▶ Drilled into bin filled with vibratory compacted lunar regolith simulant using all three, and compared drill depth to core height

LuCAS Development



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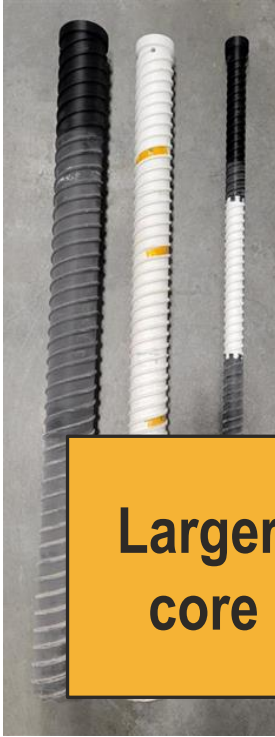


Test ID	Auger ID [in]	Auger Speed [rpm]	Percussion [0/1]	Rate of Penetration [mm/s]	Drill Depth [in]	Core Height [in]	Core Retention [%]
1	0.75	48	0	0.5	24.75	0.50	2%
2	0.75	48	1	0.5	24.13	1.875	8%
3	0.75	10	0	0.4	11.45	3.50	31%
4	0.75	10	1	0.4	11.25	5.75	51%
5	0.75	10	1	0.4	12.00	5.25	44%
6	0.75	10	0	0.4	11.25	3.75	33%
7	0.75	10	1	0.4	12.00	9.00	43%
8	1.5	60	0	1	23.50	8.75*	37%
9	1.5	60	1	1	23.15	8.25*	36%
10	1.5	10	0	0.4	11.50	6.75	59%
11	1.5	10	1	0.4	11.625	7.25	62%
12	1.5	10	0	0.4	10.38	7.45	72%
13	1.5	10	1	0.4	11.25	8.88	79%
14	2	60	0	1	23.06	2.188	9%
15	2	60	1	1	23.06	1.563	7%
16	2	10	0	0.4	11.063	6.563	59%
17	2	10	1	0.4	11.063	6.563	59%
18	2	10	0	0.4	10.69	6.81	64%
19	2	10	1	0.4	21.44	16.06	75%

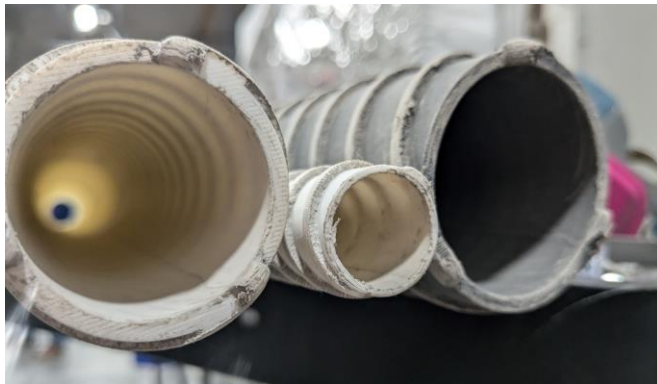
LuCAS Development



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Larger diameter and slower drilling dramatically improve core retention, and 1.5" vs 2" ID cores are very similar



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17	2	10	1	0.4	11.063	6.563	59%
18	2	10	0	0.4	10.69	6.81	64%
19	2	10	1	0.4	21.44	16.06	75%

Upcoming Work

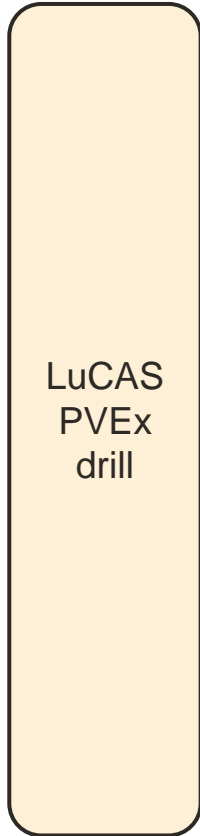


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- ▶ Intermediate diameter PVEx auger is currently being procured



2.0" ID
0.5 m long



LuCAS
PVEx
drill

1.5" ID
1.0 m long



0.76" ID
1.0 m long

Upcoming Work

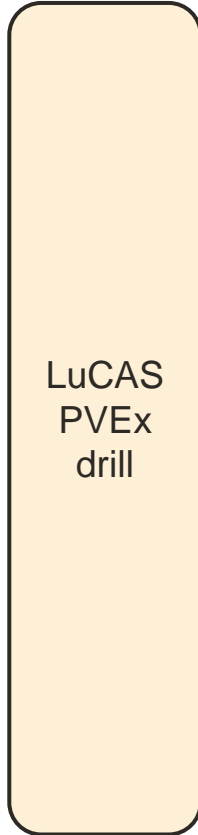


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- ▶ Intermediate diameter PVEx auger is currently being procured
- ▶ Will test in recently developed TRIDENT/VIPER testbed



2.0" ID
0.5 m long



LuCAS
PVEx
drill



0.76" ID
1.0 m long

Test Specs at a Glance

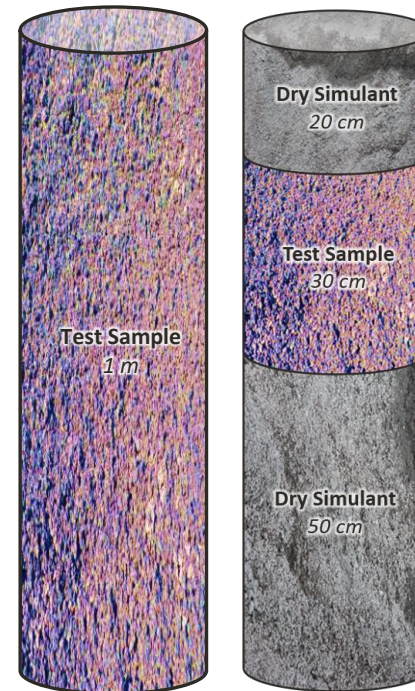
Simulant: LSP-2 or NU-LHT-2M

Ice Content: 3-12% water ice,
TBD quantity of dry ice

Ice form: Ice cemented regolith

Pressure: $\leq 1\text{E-}2$ torr

Temperature: $\leq 200\text{K}$



TRIDENT/VIPER Testbed

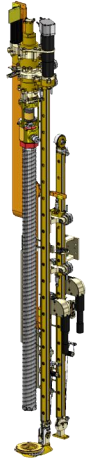


LuCAS Project Direction

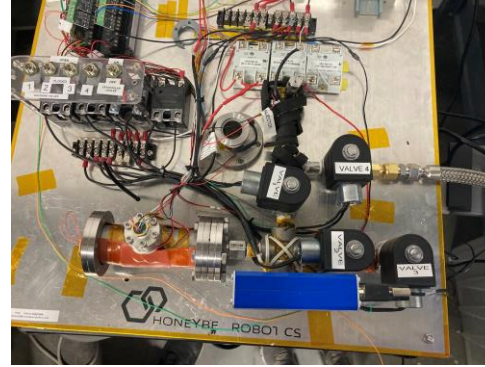


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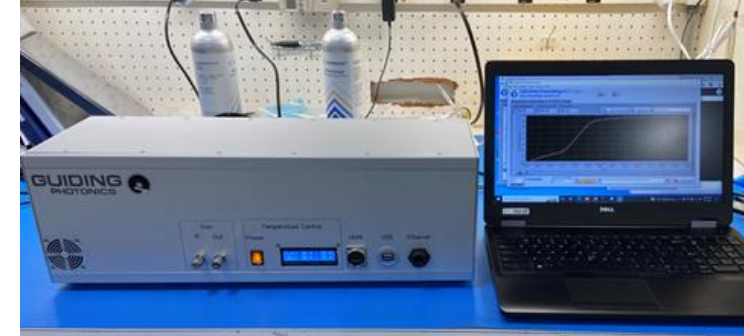
2025:



New & Improved PVEx



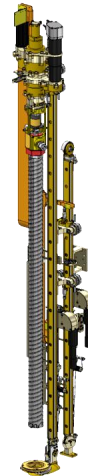
TRL 5 Sample Handling System (SHS)



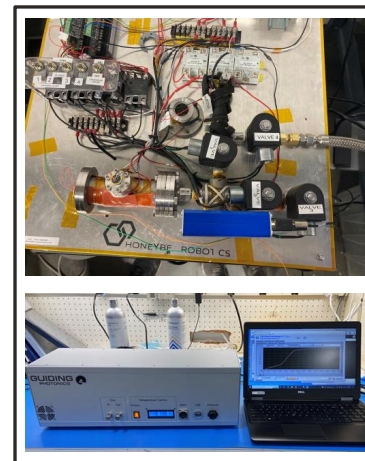
Benchtop CAS

Lessons learned from end-to-end TVAC testing with PVEx will inform full system TRL 6 design

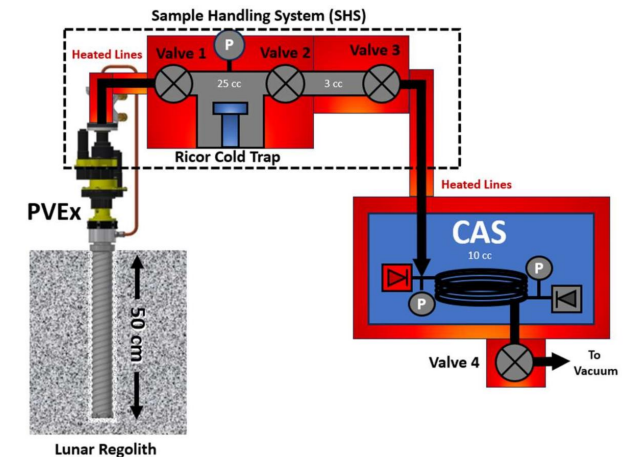
2026:



Same PVEx



Integrated TRL 6 SHS & CAS





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